



Beam Induced Depolarizing Resonances in the HERMES Experiment

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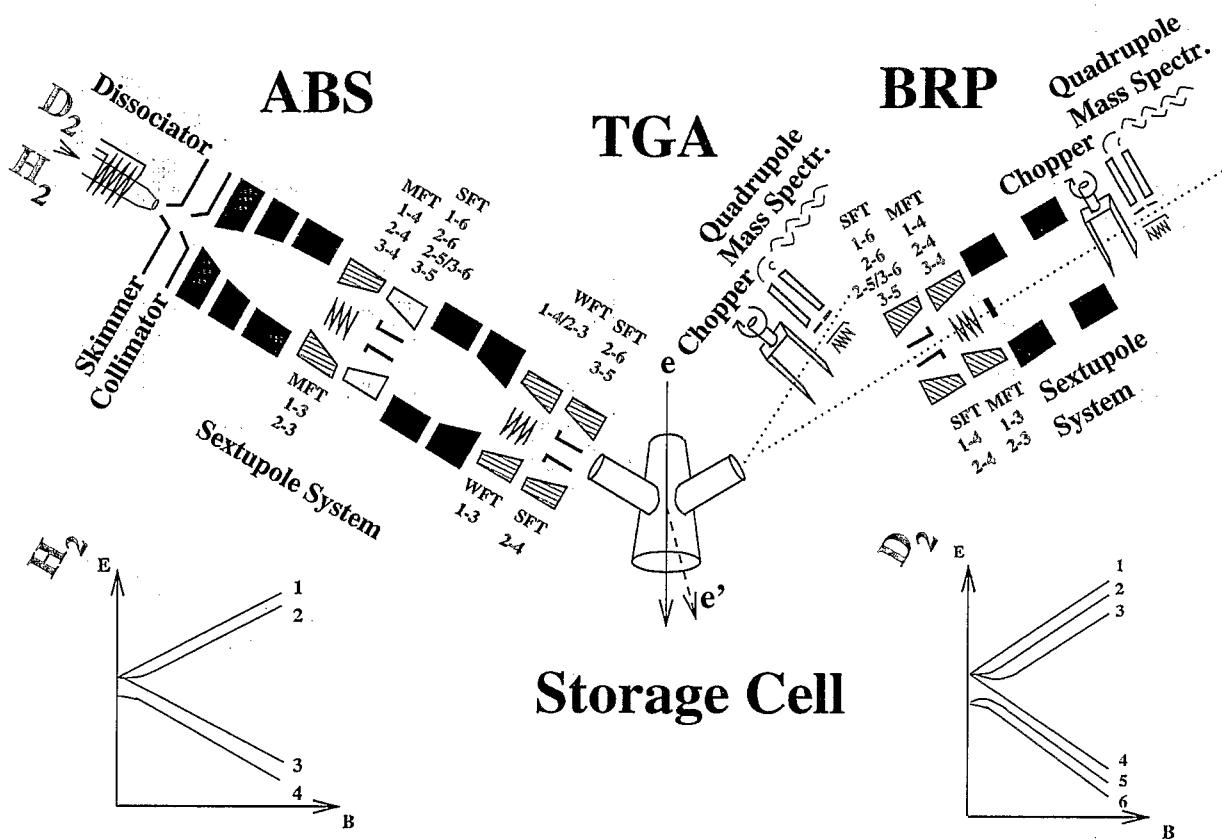
HERMES Collaboration, DESY - Hamburg

Outline:

- The HERMES Target
- Depolarization by Beam Interaction
- Resonances' Measurements
 - Longitudinal Target
 - Transverse Test Target
- The new Tranverse Polarized Target



The HERMES Polarized Target

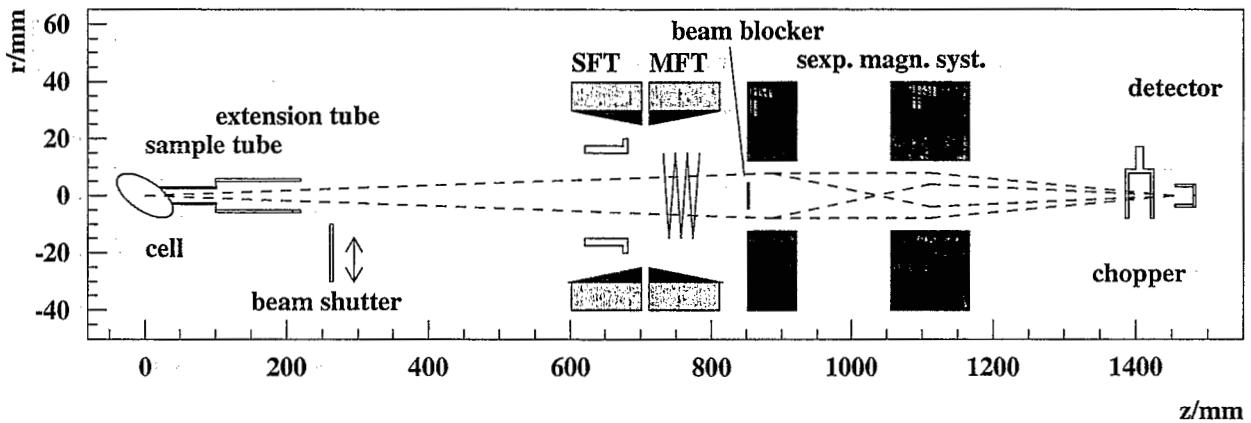


Target Setup

- Atomic Beam Source (ABS)
- Storage Cell + Magnet
(Longitudinal: 335 mT, Transverse: 297 mT)
- Breit-Rabi Polarimeter (BRP)
- Target Gas Analyzer (TGA)



The Breit-Rabi Polarimeter (BRP)



- Task:
 - Measure the polarization of sample beam
- Measurement:
 - Use of chopper to subtract background
 - Measurements with different HFT modes:
⇒ linear equations system, solution for N_i
- Calibration:
 - $N_{\text{sig}} > N_{\text{hfs}}$ ⇒ system overdetermined
⇒ RFT efficiencies can be measured
- Performance:
 - Minimum time for polarization measurement ≈ 30 s
 - Statistical uncertainty in 1 min $\leq 0.5\%$
 - Systematic uncertainty $\approx 1\%$

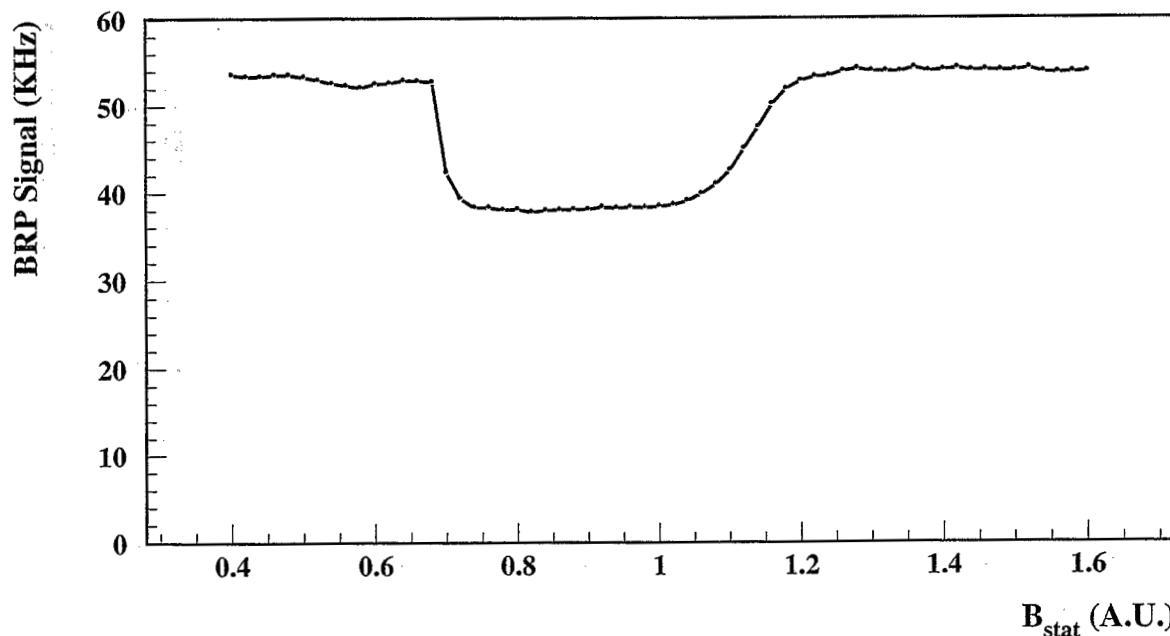
High Frequency Transitions

Hyperfine states populations exchange $|i\rangle \leftrightarrow |n\rangle$

Superimposition of an electromagnetic HF field and an external static gradient magnetic field (B_{stat}^{grad}) along the atomic beam path.

HF-field frequency fixed and B_{stat}^{grad} tuned in order to get a resonance condition between the two states in the Breit-Rabi diagram.

Gradient field \Rightarrow Adiabatic transition with efficiency ≈ 1 .



Strong Field Transitions

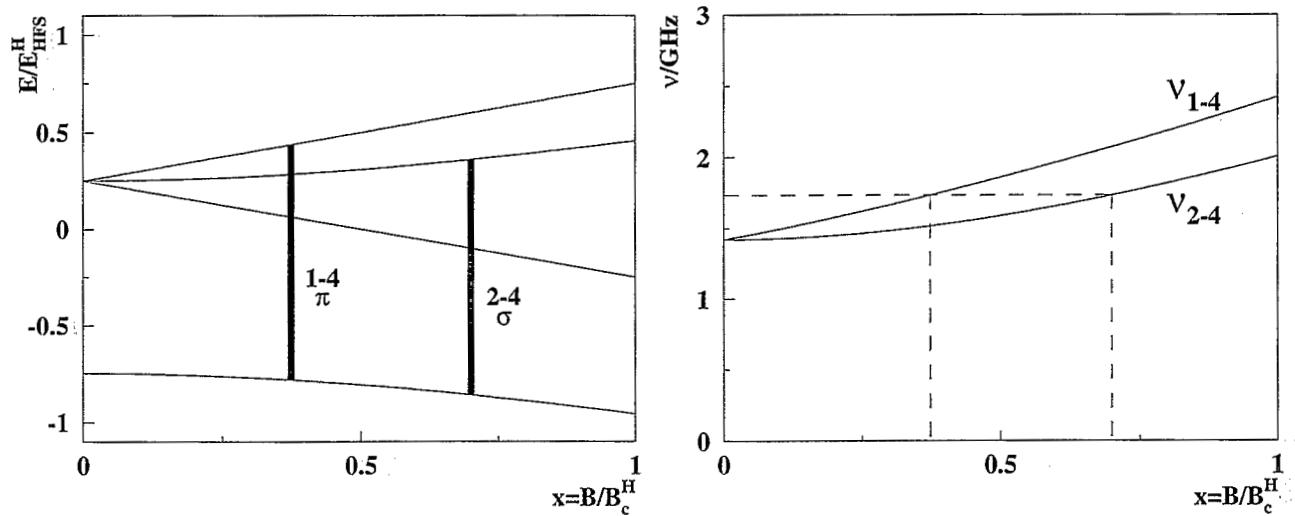
SFT exchange hyperfine states with $\Delta F = \pm 1$.

Two kinds of strong field transitions:

- π -transitions: $\Delta m_F = \pm 1 \Rightarrow B_{ST} \perp B_{RF}$
- σ -transitions: $\Delta m_F = 0 \Rightarrow B_{ST} \parallel B_{RF}$

Example: SFT resonances for atomic H at 1734 MHz.

The resonant frequency can be derived from the energy difference in the Hyperfine Splitting Diagram.



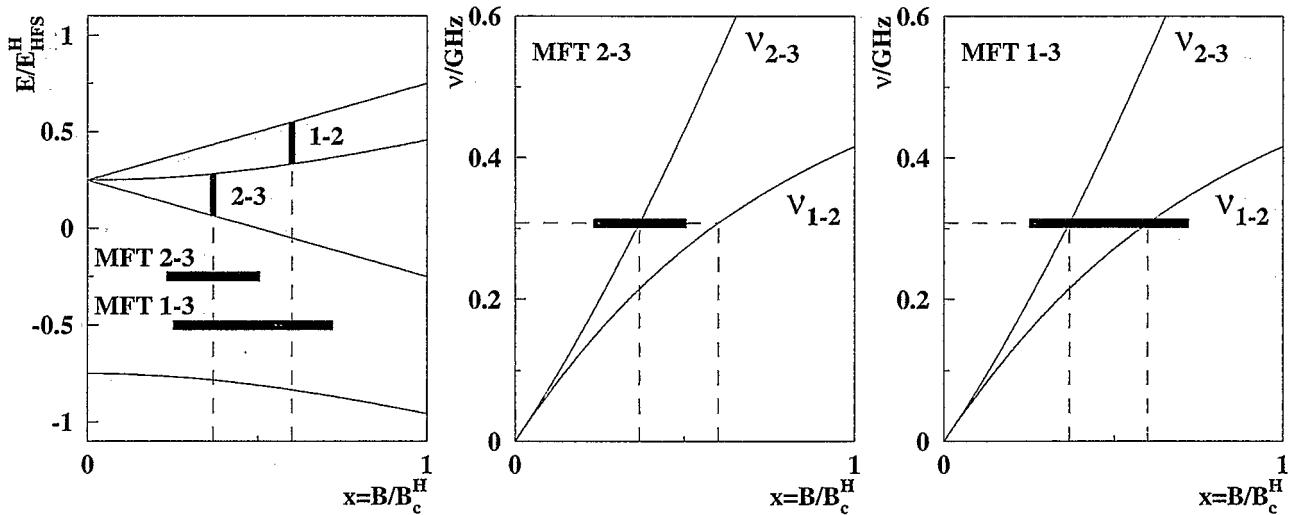
Weak/Medium Field Transitions

MFT/WFT exchange hyperfine states with $\Delta F = 0$
(i.e. transitions *within* a Zeeman-Multiplet).

$\Delta m_F = \pm 1 \Rightarrow \pi\text{-transitions only}$

Example: MFT resonances for atomic H at 308 MHz.

The horizontal bars in the Breit-Rabi diagram indicate the effective field range when superimposing a gradient field.



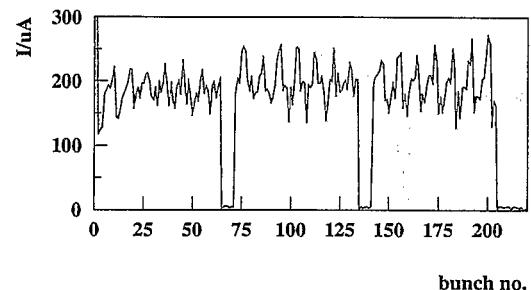
$$\Delta B_{grad} < 0 \Rightarrow \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{pmatrix} \xrightarrow{1-2} \begin{pmatrix} n_2 \\ n_1 \\ n_3 \\ n_4 \end{pmatrix} \xrightarrow{2-3} \begin{pmatrix} n_2 \\ n_3 \\ n_1 \\ n_4 \end{pmatrix}$$

$$\Delta B_{grad} > 0 \Rightarrow \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{pmatrix} \xrightarrow{2-3} \begin{pmatrix} n_1 \\ n_3 \\ n_2 \\ n_4 \end{pmatrix} \xrightarrow{1-2} \begin{pmatrix} n_3 \\ n_1 \\ n_2 \\ n_4 \end{pmatrix}$$

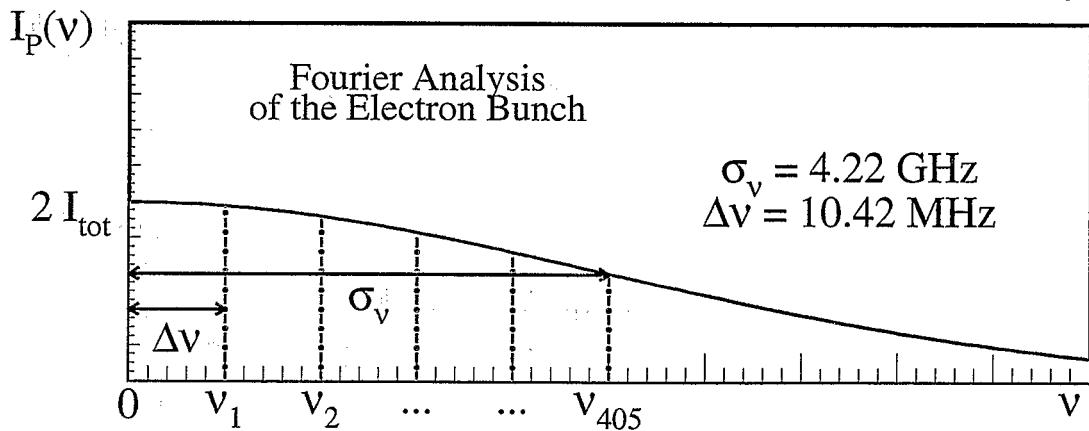
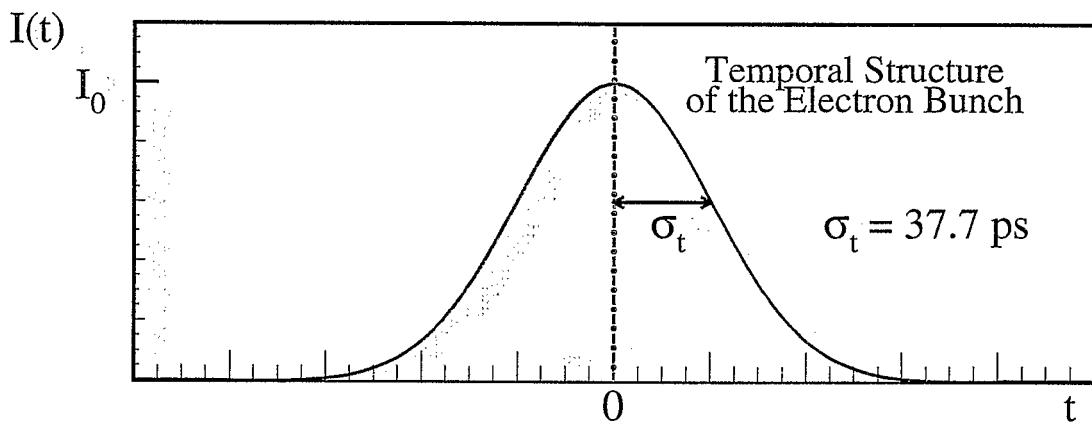
Depolarization by Beam Interaction

HERA e-beam structure:

- 220 Bunches
- Spacing: $\Delta t = 96 \text{ ns}$
- Bunch width: $\sigma_t = 37.7 \text{ ps}$



Fourier Analysis of the electron bunch:



Resonance Conditions: $\frac{|E_i - E_f|}{h} = \nu_n \quad n = 1, 2, \dots$

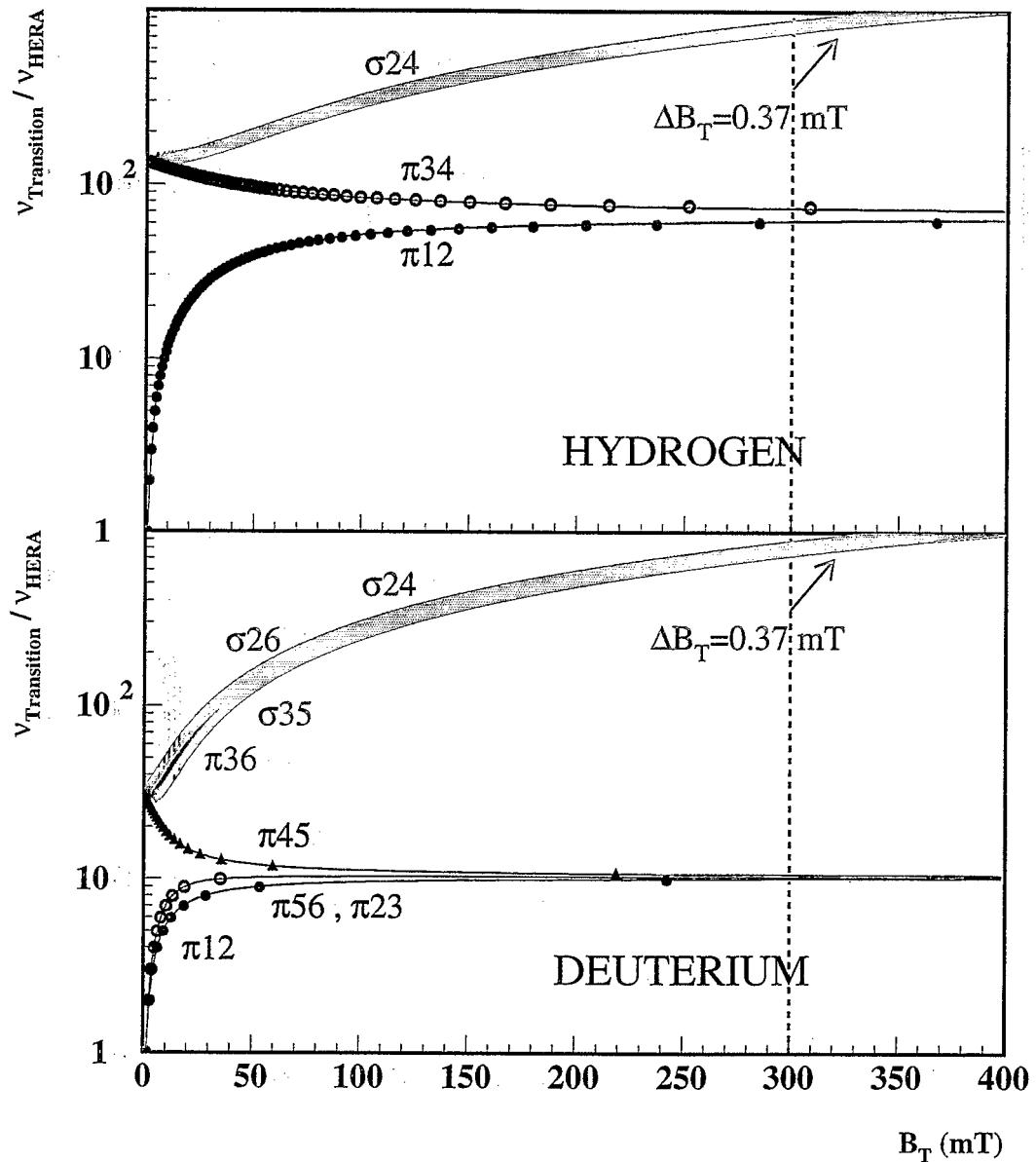
\Rightarrow Depolarization!



Resonance Conditions (Nucl. Trans.)

$$|E_i - E_f|/h = \nu_n \quad n = 1, 2, \dots$$

But... ΔE_{if} depends on B_{ST} !



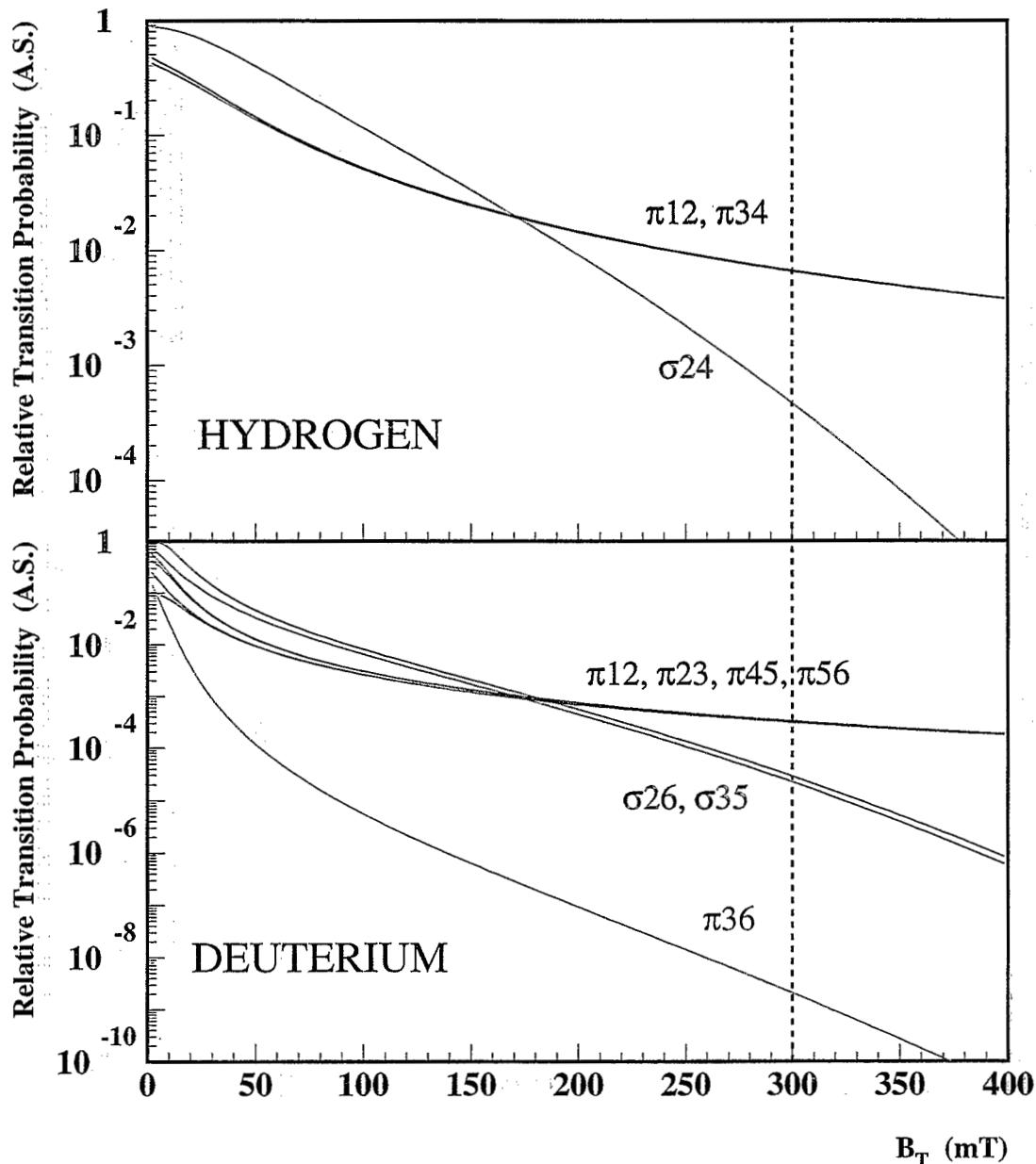
- π -transitions ($B_{ST} \perp B_{RF}$) \Rightarrow Long. & Trans. Target
- σ -transitions ($B_{ST} \parallel B_{RF}$) \Rightarrow Trans. Target Only!

Relative Transition Probabilities

$$W_{if} \propto B_{RF}^2 \cdot |V_{if}|^2 \cdot \tau^2$$

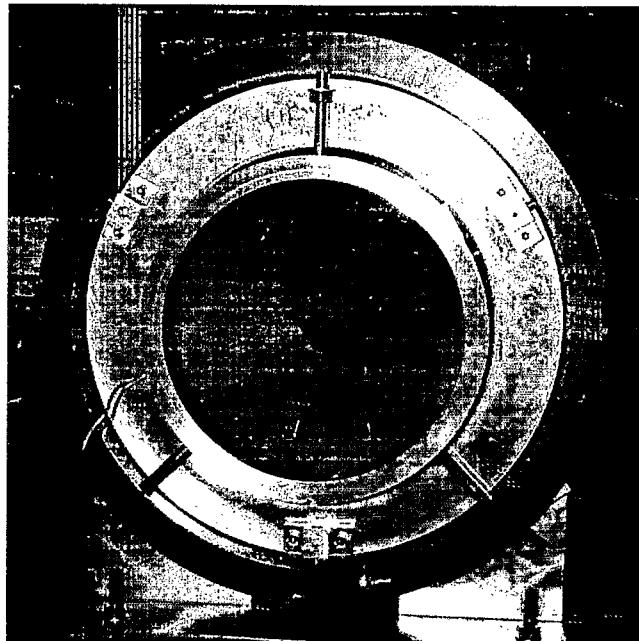
- B_{RF} depends on the harmonic number (for a given beam current)
- The harmonic number depends on B_{ST}

Fixing τ and evaluating $|V_{if}|^2 \Rightarrow W_{if}$ vs B_{ST} :

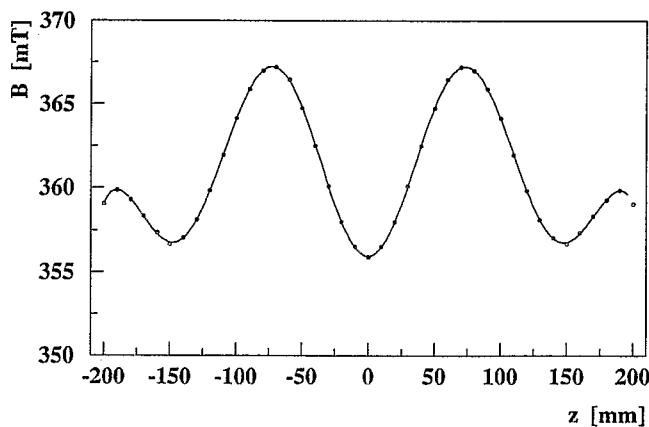


The Longitudinal Target Magnet

- 1996-1997 → Longitudinally polarized H Target
- 1998-2000 → Longitudinally polarized D Target



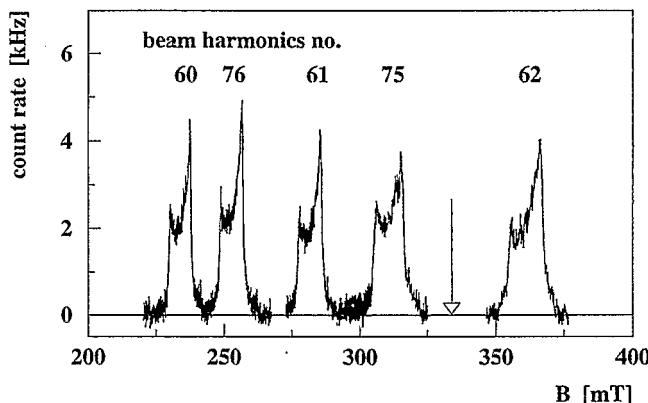
- The Magnet: four superconducting coils mounted coaxially to the HERA e-beam
- The Field: up to $400 \text{ mT} \pm 2\%$



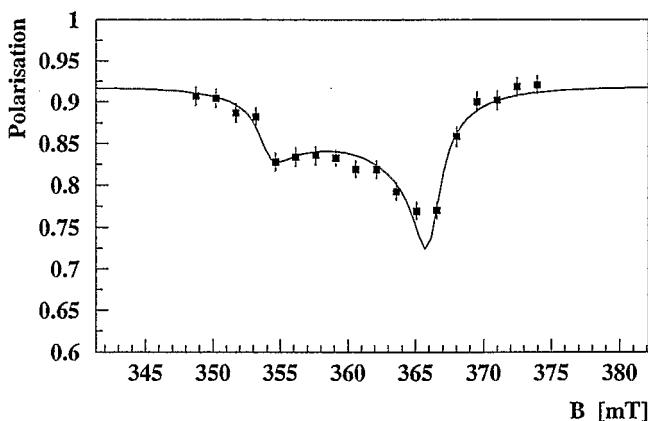
Beam-Induced Nuclear Depolarization in the Long. Pol. Hydrogen Target

Possible Depolarizing Resonances: $\pi 12$, $\pi 34$

- Spin-Flip Measurements:
 - States $|1\rangle$ and $|4\rangle$ injected (ABS)
 - Target Field scanned from 220 mT to 400 mT
 - Fast detection of states $|2\rangle$ and $|3\rangle$ (BRP)



- Polarization Measurements
 - States $|1\rangle$ and $|4\rangle$ injected (ABS)
 - Target Field scanned within the 62^{th} harmonic resonance
 - Accurate Polarization Measurement at each step (BRP)

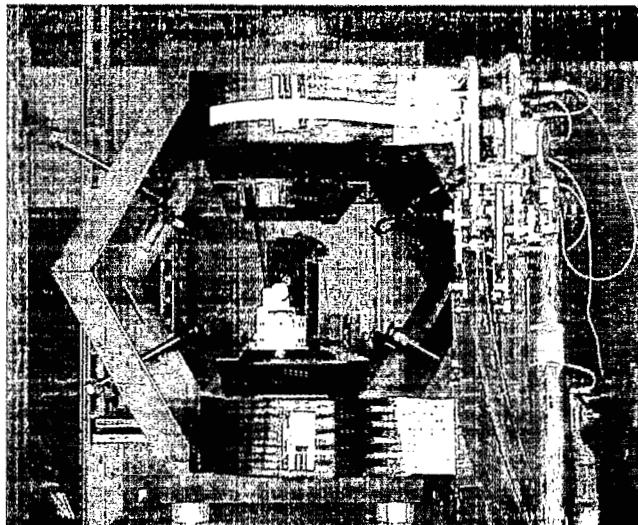


K. Ackerstaff et al., Phys. Rev. Lett. 82 (1999) 1164-1168

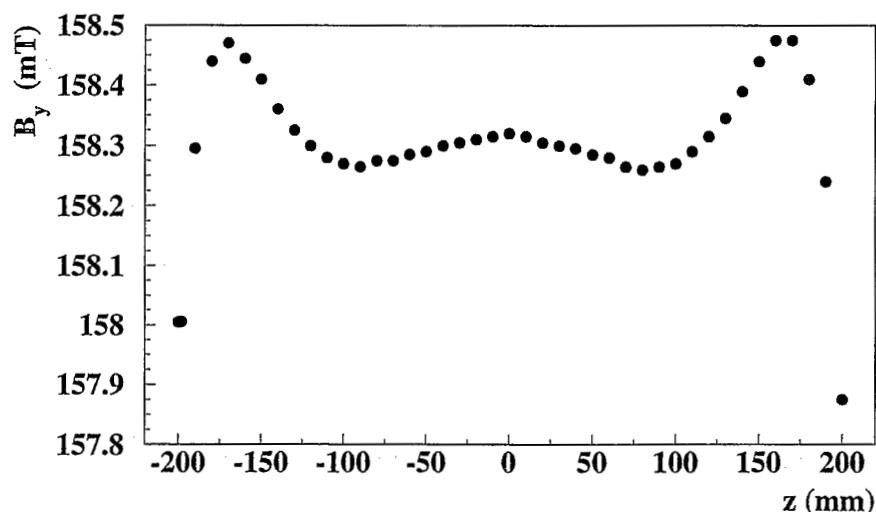


The Transverse Test Target Magnet

- June 1999 → Transverse polarized H Test Target



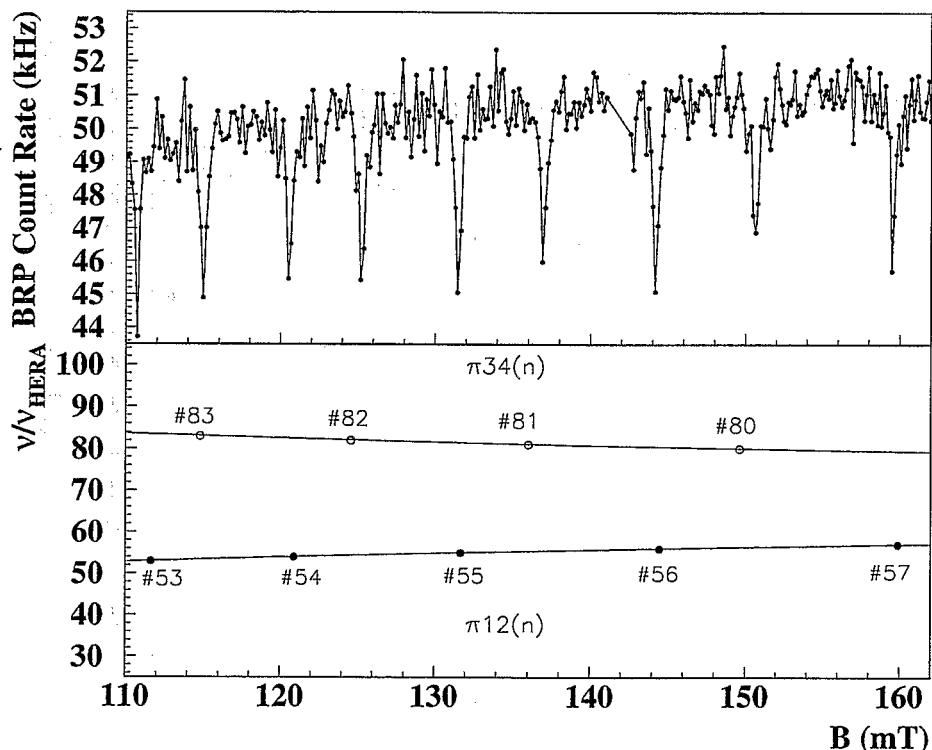
- The Magnet: Water cooled Conventional Dipolar Magnet
- The Field:
 - Intensity: up to 180 mT
 - z-Uniformity: 0.6 mT @ $B = 150$ mT



Beam-Induced Nuclear Depolarization in the Trans. Pol. Hydrogen Test Target

Possible Depolarizing Resonances: π_{12} , π_{34} , σ_{24}

- Spin-Flip Measurements
 - States $|2\rangle$ and $|3\rangle$ injected (ABS)
 - Target Field scanned from 110 mT to 162 mT
 - Fast detection of states $|2\rangle$ and $|3\rangle$ (BRP)

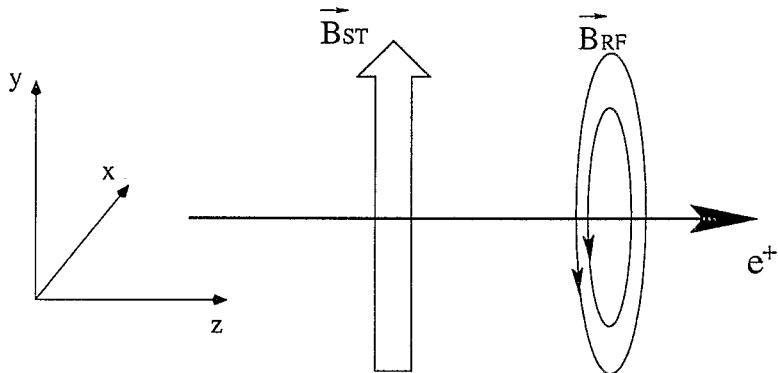


- Polarization Measurements
 - Not possible due to the current BRP deuterium setting
- No beam-beam Measurements Comparison (σ_{24} detection)
 - Not successful due to a BRP Failure



The Transverse Polarized Target

From July 2001 → Transverse Polarized Target (H)



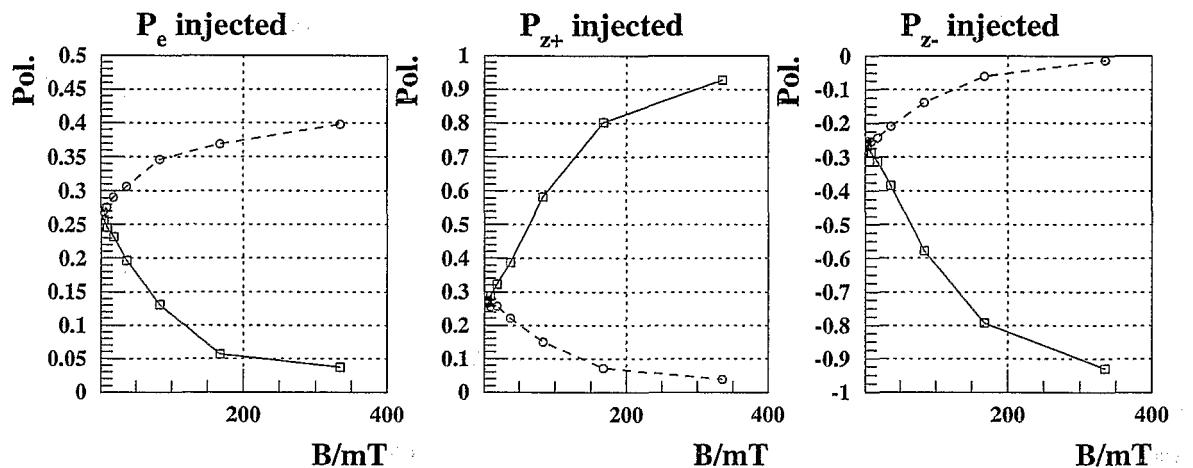
New Target Holding Field

Drawbacks and Solutions:

- Bending of the electron beam:
Orbit compensation
- Syncrotron radiation emission:
Avoid the spectrometer acceptance
- Possible beam induced nuclear depolarization:
Conceive an holding field which minimizes this effect

The Magnet Design

- Conventional static vertical dipole
- $B_T > 280 \text{ mT}$ to inhibit spin relaxation

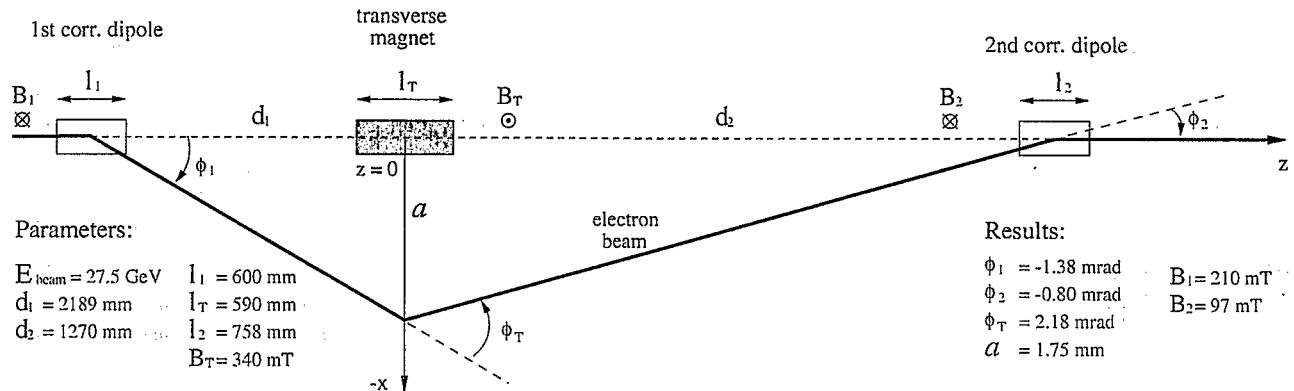


- $B_T < 400 \text{ mT}$ to minimize synchrotron radiation
- $\Delta B < 0.15 \text{ mT}$ overall the cell region ($400 * 20 * 10 \text{ mm}$), to avoid beam induced depolarization
- Dimensional constraints:
 - pole length $< 650 \text{ mm}$
 - pole width $< 200 \text{ mm}$

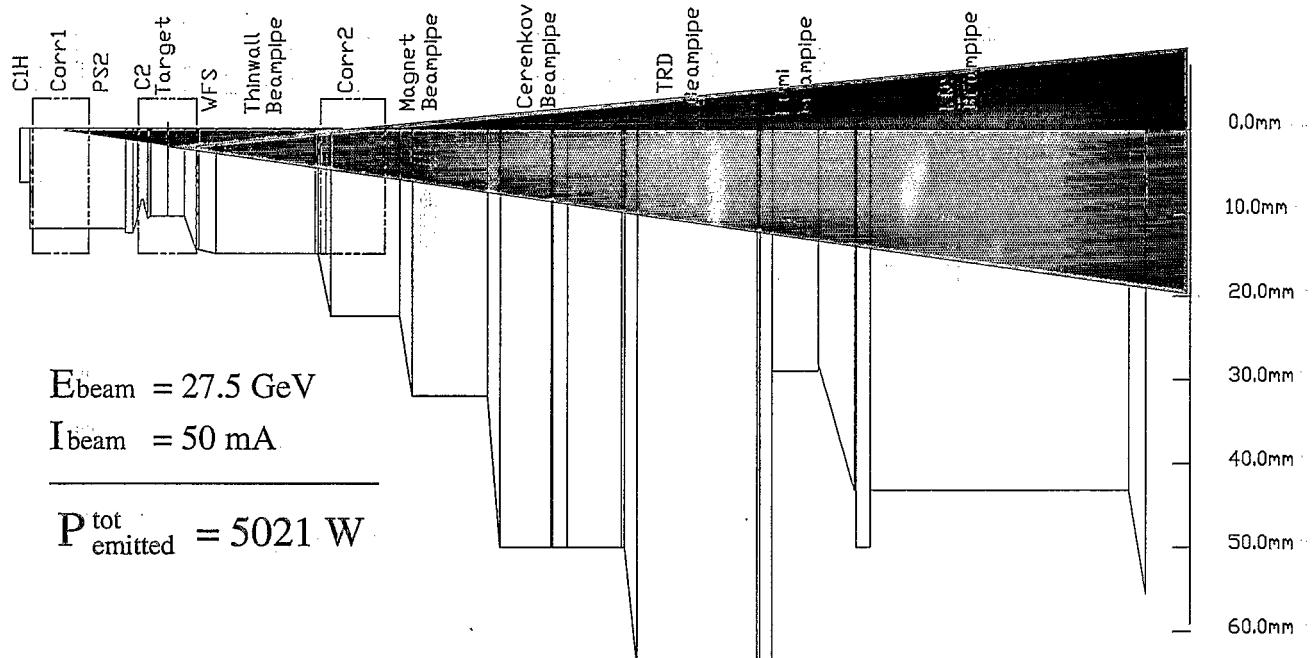


The Effects on the HERA Beam

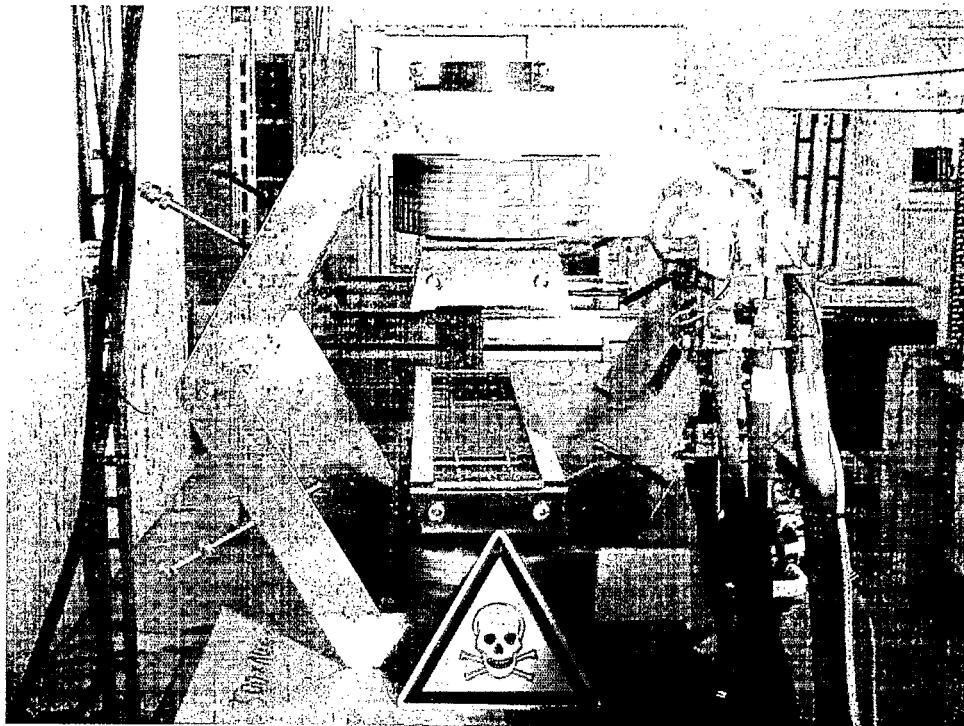
Bending ($B_T = 340 \text{ mT}$):



Synchrotron radiation ($B_T = 340 \text{ mT}$):



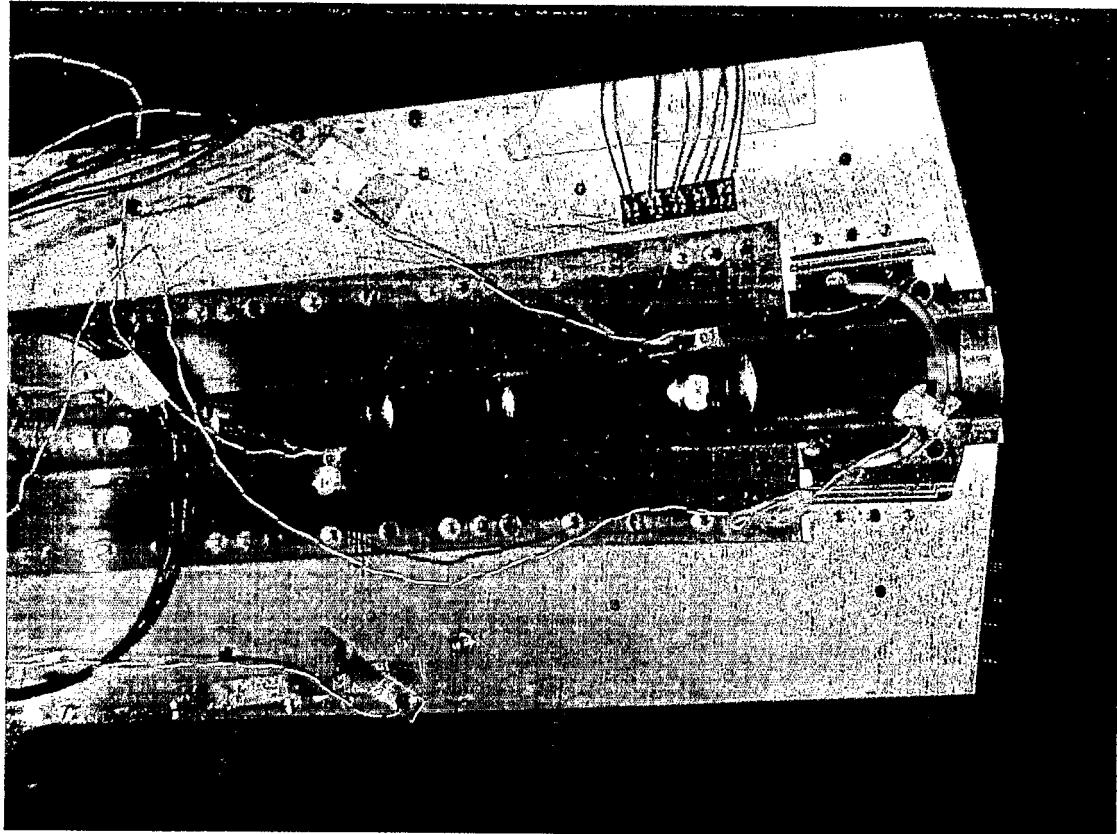
The Transverse Magnet



- Field intensity: $B_T = 297 \text{ mT} @ 545 \text{ A}$
- Requested field uniformity:
 $< 1.4 \text{ gauss}$ overall the cell region
- Actual uniformity:
 - ΔB along z : 0.5 gauss
 - ΔB along y : 1.5 gauss
 - ΔB along x : 6 gauss
- Additional correction coils needed?
Answer from a depolarizing resonance test performed with a high current e^+ beam ($I > 30 \text{ mA}$)

The Correction Coils

Cell with built-in correction coils ready in Ferrara



- Two coils at ± 18 mm from the xz axis
- Current: $I \approx 70$ A
- Overall Field Uniformity: $\Delta B \leq 1.5$ gauss
- Improved Field Tuning

Transverse Target Summary

- Transverse Magnet built and installed
- Target preliminary tuned
- Atomic nuclear polarization $\approx 85\%$
(e^+ beam current $\leq 15 \text{ mA}$)
- Beam induced depolarization test:
as soon as e^+ beam current $\geq 30 \text{ mA}$
- Target Cell with built-in Correction Coils
manufactured and tested

